the Half-Integer Charged Particles of the Orbifold Models

Cheng-Yi Sun[*,a] **and De-Hai Zhang**[†,b]

[a]Institute of Modern Physics, Northwest University,
Xian 710069, P.R. China.

[b]Department of Physics,
Graduate School of Chinese Academy of Sciences,
Beijing 10049, P.R.China.

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Abstract

In this paper, we consider half-integer charged particles predicted by models of orbifold compactification of the $E_8 \times E_8$ heterotic string theory. We find that it is possible for half-integer charged particles to exist in our universe, and the location of half-interger charged particles in a galaxy should be in the centers of the galaxy. By qualitative analysis, we find half-interger charged particles may be helpful in explaining the formation of SMBH at the large redshift and solving the UHECR puzzle.

1 Introduction

In the last decade, the great improvement has been made in cosmology, which leads to the so-called "concordant cosmological model". The con-

*ddscy@163.com; cysun@mails.gucas.ac.cn
†dhzhang@gucas.ac.cn

cordant cosmological model, together with the *Standard Model* of particle physics, represents our current understanding of the nature. The later can be extended slightly by neutrinos with nonzero masses, and the former is extended excellently by inflation. However, there still exist lots of questions and challenges to the concordant cosmological model and the *Standard Model*, in spite of their impressive successes. For example, why does this particular pattern of the fundmental interactions (the electromagnetic, weak, strong and gravitational interactions) exist in the nature? Why is the total rank of the electroweak-strong gauge group just four? Why are there exactly three generations of particles? What's the nature of the dark matter and the dark energy? What is the mechanism that generates the baryon asymmetry? How to incorporate the inflation with the *Standard Model* properly? Then we can conclude that the concordant cosmological model and the *Standard Model* are not the end of the story, but the tip of the iceberg. A more fundmental theory is expected.

Several promising ideas have been put forward: Supersymmetry, Supergravity, Superstring/M theory and Loop quantum gravity. Among these ideas, the superstring/M theory is supposed to be the most compelling one. This theory has some excellent properties: no UV divergence, including gravity and gauge interaction automatically, no free parameters before compactification, uniqueness (different string theories are dual to each other, as a whole), etc.. However the superstring/M theory requires a definite number of space-time, 10/11. To reconcile with our empirically 4-dimensional universe, the extra 6/7 dimensions have to be compacted. Unfortunately, it is argued that there may exist lots of approaches of compactification. This even leads some authors to suggest the scenario, Landscape [1]. In this scenario, it is argued that there exist plenty of vacua, at the order of 10^{500}, as the result of different models of compactification [2], and the *Standard Model* can be constructed in some vacua.

Briefly, there are three classes of models on building the *Standard Model* within the framework of the superstring/M theory: intersecting D-brane models [3], Calabi-Yau models [4] and orbifold models [5, 6]. Calabi-Yau (orbifold) models are based on the $E_8 \times E_8$ heterotic superstring theory with Calabi-Yau (orbifold) compactification. In some sense, orbifold models can be taken as the limitation of Calabi-Yau models. Many models on building the *Standard Model* in string theory have been suggested. Although none of the models is accepted by the majority, we think some models are worth studying further. For example, in Ref.[8, 9], some nice orbifold models have

been suggested.

In orbifold models, due to the six extra-dimensions and the lattice group, $E_8 \times E_8$, the maximum rank of gauge group is limited to be 22, while the rank of gauge group in intersecting D-brane models is unlimited. Then This property reduces the arbitrary of orbifold models greatly. Usually, in the orbifold models, the orbifold is constructed from the torus T^6 by identifying the points under a discrete point group. Once the point group is given, there are only a few possible sets of the shift vectors and the Wilson lines from which the unequivalent breaking patterns of E_8 are deduced [7]. When the shift vector and the Wilson line are given, the unbroken gauge group derived from E_8 is definite. Then by exhausting all the possibilities, we can select the appropriate breaking patterns which lead the (supersymmetric) Standard Model gauge group and matter content.

In the models of Ref.[8, 9], the authors obtain the 3 chiral matter generations including the right-handed neutrinos, plus the singlet and vector-like exotic matter. Particularly, in [9], the authors construct a three-family flipped SU(5) model from Z_{12-I}. By the Yukawa couplings, the model provides naturally the R-parity, the doublet-triplet splitting, and one pair of Higgs doublets. The model also contains some superheavy singlets, which can be the excellent candidates for inflation fields. So far, in the model of [9], no serious phenomenological problem is encountered.

But a remarkable property of this model is that it predicts half-integer charged particles! From now on, We call half-integer charged particle as *halfon*. In fact, this is a common property of orbifold models. However, it is well known that no signal of the existence of fractional charged particles has been observed. Fortunately, in the model of [9], due to the broken U(1) symmetries at the GUT scale, the halfons are superheavy naturally with mass at the order of 10^{16}Gev. Because of the half-integer charge, the lightest of halfons, labeled by $S^{\pm 1/2}$, must be stable. Then it is possible that $S^{\pm 1/2}$, as the stable particles predicted by orbifold models, may exist in our universe, and imprints of halfons in the universe would be observed in the future.

However, we know the existence of fractional electric charged particles are limited severely by observations, particularly by the Millikan oil drop experiments. In [10], it is shown that The concentration of particles with fractional charge more than 0.16e (e being the magnitude of the electron charge) from the nearest integer charge is less than 4.17×10^{-22} particles per nucleon with 95% confidence.

Then, in order to alleviate the limitation, generally, it is argued that most

of halfons are diluted away by inflation if the mass of LHIC is much larger than the reheating temperature. The case is similar to monopoles. Because density of halfons becomes so low after inflation, we can not observe halfons on the earth. So the contradiction between the observation and the existence of halfons in physics is eliminated.

But, there exists another possibility that the density of halfons may be not low. We can not observe halfons on the earth just because halfons do not locate on the earth. Then, if halfons do not locate on the earth, where can they locate? If halfons do exist in our universe, are there any observable imprints? Will halfons be helpful in solving some present puzzles in cosmology? After extensive consideration of these questions, we find that, if we assume appropriate halfons generated by the reheating, halfons should condense in the center of each galaxy. Our solar system is away from the center of the Milk Way Galaxy, so halfons can not be observed on the earth. Further we find that, at the centers of galaxies, the annihilation of $S^{1/2}$ and $S^{-1/2}$ can happen, and this may explain the origin of the ultra-high energy cosmic rays (UHECRs) above the GZK cutoff [12]. Even, because of the electric charge, $S^{\pm 1/2}$ may form bound states by attracting protons or electrons. Particularly, $S^{1/2}$ and e^- can form the bound state $S^{1/2}e^-$. The state has one spectral line with the wavelength of 4680Å, which is slightly different from the spectral line of Hydrogen atom with the wavelength of 4682Å. If this spectra line is observed, the interesting would be very great.

Below, let's show our consideration in detail. The paper is organized as follows. In Section 2, by analyzing the procession of the formation of the large scale structure, we show that most of halfons should locate at the center of galaxies. In Section 3, we consider some implications of halfons in cosmology.

2 Condensation of Halfons

Firstly, we assume the density of halfons generated by reheating is appropriate. In the model of [9], the particle content is definite. If the inflation fields are taken as the singlets in the model, the coupling between halfons and inflation fields can be deduced naturally. Then halfons should be generated during reheating by the coupling. The number density of halfons is determined by the mass of halfon and the temperature of reheating. Then, by choosing parameters, appropriate halfons can be generated. So we think our

assumption is reasonable. Denoting the present ratio of density of halfons by Ω_S, we expect $10^{-6} < \Omega_S < 10^{-2}$. If $\Omega_S > 10^{-2}$, the big bang nucleosynthesis will be effected. If $\Omega_S < 10^{-6}$, the imprints of halfons in the universe may be too weak to be observed.

We know the formation of the large scale structure is dominated by the cold dark matter. Presently, a galactic halo is mainly composed of baryonic matter and a huge cold dark matter halo. Generally, it is supposed that the configuration of the dark matter is virialized. The virial velocity is about at the order of $10^2 km/s$. On the other hand, the baryonic matter, due to the ability of dissipation, forms objects of atrophysical size as individual and distinct entities in the core of the galactic halo. Then what about halfons?

In order to answer this question, let's recall the process of the formation of a galaxy in an ideal model. We know, the formation of the large scale structure begins when the universe becomes the matter-dominated. After the last scattering, the baryonic matter falls into the well of the gravitational potential formed by the cold dark matter. When $(\delta\rho/\rho)$ becomes of order unity, the cluster which forms the galaxy eventually, separates from the expansion of the universe. Then the cluster begins to contract and collapse. At the beginning of the contraction, due to the cosmological expansion, the velocities of the cluster matter can be taken as zero roughly. For simplicity, we assume the cluster is roughly spherically symmetric. Then the cluster matter, including cold dark matter, baryonic matter and halfons, begins to fall towards the center of the cluster roughly along the radiuses under the attraction of gravitation. If we neglect the interaction and collision, the cluster particles would oscillate between the antipodal points for long time. In fact, the existence of the collision and interaction will disturb the oscillating and virialize the cluster inevitably. However, the process of virialization for cold dark matter, halfons or baryonic matter is different.

For baryonic matter, due to the strong and electromagnetic interaction, the particles of the baryonic matter collide each other violently and frequently as falling towards the center. Then the virialization of the baryonic matter is completed long before the dark matter. The phase space distribution of the virialized baryonic matter becomes roughly Maxwellian and their density varies roughly as r^{-2}. Such a configuration is often referred to as an isothermal sphere. The random distribution of the velocities of the virialized particles would prevent the baryonic matter from contracting further. But, due to the dissipative process–e.g., collisional excitation of atoms and molecules, and Compton scattering off the CMBR, the baryonic matter can

lose energy and condense further into the core of the cluster. Finally, objects of astrophysical size are formed as individual and distinct entities. If the galactic halo has the angular momentum, after dissipation, the baryonic matter will wind up in a disk-like structure [13].

For dark matter, the virialization is later than the baryonic matter. Generally, the cold dark matter particles are supposed to be weak-interaction massive particles (WIMPs). Due to the WIMP model, the cold dark matter cannot be virialized by colliding with each other or the baryonic matter. However, the galactic halo is not spherically symmetric definitely. And the time- and pace-varying gravitational field provides the means for WIMPs to change their momentums and to become well mixed in phase space. Particularly, as the condensation of the baryonic matter, Many local gravitational centers are formed. Then the gravitational scattering of the cold dark matter particles by the local centers accelerates the virialization greatly. After a few dynamical times ($\tau \sim (G\rho)^{1/2}$), the virialization of the cold dark matter is finished [13]. However, as the result of the WIMP model, the virialized cold dark matter cannot lose energy to condense and collapse further. So, now the configuration of the cold dark matter is still a virialized halo.

For halfons, the case is different from both baryonic matter and cold dark matter. The coupling between halfons and dark matter can happen only by the weak neutral current, which is very weak. So halfons almost do not collide with the cold dark matter. Since halfon has the half-integer electric charge, it follows that halfons can be involved in the electromagnetic interaction. So, as falling towards the center of the cluster, halfons must collide with the baryonic matter by the electromagnetic interaction. Due to the superheavy mass, the effect of one collision on the motion of halfon is unobvious. However, near the center of the cluster, the density of the baryonic matter becomes very high. Then, near the center, the frequent collisions between halfons and baryonic matter can evidently reduce the kinetic energy of halfons. At the same time, the configuration of the baryonic matter can be taken as a isothermal sphere. So, roughly, the motion of halfon may be taken as a damped oscillator along a radius. Then only after several oscillations, halfons may lose most part of their kinetic energy. The velocities of halfons become so small that they cannot move away from the cluster center. In some sense, we can say that halfons are virialized and become one part of the configuration of the virialized baryonic matter at the cluster center. After then, halfons, together with baryonic matter, condense and contract further. Finally, halfons become one part of the individual and distinct objects with

astrophysical size near the cluster center. We think, due to the superheavy mass, the locations of halfons should be at the centers of these objects.

Additionally, due to electromagnetic interaction, halfons and electrons (protons) can form some bound states, $S^{-1/2}p^+$, $S^{1/2}e^-$, etc. These states make halfons have the ability to undergo dissipation, as the baryonic matter, to lose energy. Even, due to the electron/proton cloud around $S^{1/2}/S^{-1/2}$, the scattering cross section of these states is much bigger than that of halfons. Then it implies that, after having been combined with electrons or protons, halfons collide with the baryonic matter much more frequently. So these bound states can accelerate the condensation of halfons.

In fact, we find that these bound states may have other remarkable implications. For example, the ground state energy level of $S^{1/2}e^-$ is about at the order of $10eV$, while the ground state energy level of $S^{-1/2}p^+$ is about at the order of $10keV$. Then the collisionally excited state of $S^{-1/2}p^+$ can emit photons with much higher energy than that of $S^{1/2}e^-$. It implies that $S^{-1/2}p^+$ can lose energy quicker than $S^{1/2}e^-$. Then, finally, there may exist the segregation between the two states, from which some new physical phenomenons may arise.

Particularly, the spectral line, $1s \to 2p$, of $S^{+1/2}e^-$ is very close to the spectral line, $2s \to 4p$, of p^+e^-. However, due to the superheavy mass of $S^{+1/2}$, the reduced masses of $S^{+1/2}e^-$ and p^+e^- are different. So the two spectral lines are not degenerate. The wavelength of the spectral line of Hydrogen atom is about 4862Å, while the wavelength of the spectral line of $S^{+1/2}e^-$ is about 4860Å. Then it becomes very interesting to find whether, in our universe, there exists the new spectral line with the wavelength 4860Å or not.

Additionally, there may exist neutral states, e.g. $(S^{-1/2})^2p^+$ and $(S^{+1/2})^2e^-$. We think that it should also be interesting to calculate the spectra of these states and then to try to find these spectral lines in our universe.

Above, in an ideal model, we show that the location of halfons in a galaxy should be at the center of the galaxy. For our Milky Way galaxy, the case is more complicated and special. Our galaxy is very huge, but the black hole at the center is small. This implies that the formation of the Milky Way is special. The early stage of our galaxy is the merging epoch of many dwarf galaxies, but the merging epoch ended early. The late stage of the Milky Way is astonishingly peaceable. In these dwarf protogalaxies, we think, halfons should locate at the centers of the protogalaxies. Then, in the Milky Way, most of halfons should locate in the spheroidal core of our galaxy. Although

the core of the galaxy may eject the baryonic matter during the active epoch, few halfons may exist in the spiral arm away from the core of the galaxy. The solar system, which may be formed by some ejected matter, is far away from the core. So very few halfons may exist in the solar system. Then, we think, this is the reason that, on the earth, no signal of fractional electric charged particles has been observed.

3 Implications of Halfons

In the last subsection, we have given one of the implications of halfons, the spectrum line with the wavelength 4860Å. If the spectrum line is observed, the interesting is obvious.

Additionally, We find that halfons may be helpful in solving the UHECR puzzle. Due to the GZK cutoff, the UHECR spectrum should dramatically steepen above $E_{GZK} \approx 5 \times 10^{19} eV$. However, a significant excess of events above $10^{20} eV$ has been detected. Many proposals, including top-down models, have been suggested to solve this puzzle (for a review, see [12]). Top-down model is a generic name for all proposals in which that the observed UHECR primaries are produced as decay products of some superheavy particles X with mass $m_X \gtrsim 10^{12} GeV$. The superheavy particles may be produced by topological defects such as cosmic strings, monopoles and hybrid defects, or be superheavy metastable relic particles. But the both approaches have the fine-tuning problem. For the latter, the lifetime of the superheavy particle should be fine tuned to be in the range $10^{17}s \lesssim \tau_X \lesssim 10^{28}s$. For topological defects, the case is even worse, because topological defects is constrained by observation severely.

However, if the superheavy particl is halfon, the fine-tuning problem can be solved naturally. Halfons are stable, and $S^{\pm 1/2}$ can annihilate into photons or Z bosons, $S^{1/2} + S^{-1/2} \rightarrow \gamma$ or Z. We know that it is very difficult for the annihilation of $S^{\pm 1/2}$ to happen because of the small number density and the small annihilation cross section. But we have shown in last subsection that most of halfons should condense into the center of a galaxy. Then, at the centers of galaxies, the number density of halfons may be large enough and make it possible for $S^{\pm 1/2}$ to collide with each other and then to annihilate. The mass of $S^{\pm 1/2}$ is at the order $10^{16} GeV$. Then the annihilation may produce photons or Z bosons with the energy above $10^{24} eV$. By colliding with particles around, these bosons can produce particles with ultra high energy

(UHE) above $10^{23}eV$ as secondaries, part of which may be UHE neutrinos or neutralinos. These UHE neutrinos or netralinos can traverse the extragalactic space without attenuation, thus avoiding the GZK cutoff. Then the UHE neutrinos can collide with particles in the galaxy, e.g. background neutrinos or neutralinos, and produce protons with energy above $10^{20}eV$. The protons can be the UHE primaries initiating the observed air showers and cause the UHECRs above the GZK cutoff. Additionally, the annihilation of $S^{\pm 1/2}$ happens at centers of galaxies. Then the isotropic distribution of galaxies in the universe can explain the isotropy of UHECRs naturally. So qualitatively, the idea works well. Of course, the further work is needed to make sure whether halfons can solve the UHECR puzzle quantitatively or not.

And, due to the condensation and the large mass, halfons may explain the formation of the supermassive black hole(SMBH) at the very high redshift. We know, the structure formation in the cold dark matter model proceeds hierarchically, "from the bottom up". This means bigger structures form through tidal interaction and mergers of smaller objects. Then the formation of SMBH at the high redshift requires that the efficiency of the mergers should be high enough or origin small objects should be heavy enough. Yet no one has proposed a concrete mechanism for converting stellar mass objects into objects 6 to 10 orders of magnitude larger or for generating origin small objects big enough [11]. Halfons, because of large mass and quick condensation, may be the natural candidate to generate the massive seeds to form SMBH. So it is interesting for further work to make sure whether the idea works or not.

4 Discussion and Summary

Above, we have shown our study on halfons. We find that halfons can exist in out universe by condensing into the centers of galaxies. And, we have analysed several potential implications of halfons: the spectral line with wavelength 4860Å, solving the UHECR puzzle and explaining the formation of SMBH at the high redshift. Superheavy halfons are the special prediction of the orbifold models built within the framework of the superstring/M theory. If the spectral line with wavelength 4860Å is observed, it will support strongly the orbifold models and the superstring/M theory. We know, up to date, no observational or experimental clue in supporting the superstring/M theory is found. This may be the first observable signal of the superstring/M

theory.

Additionally, besides the half integer charged particles, the orbifold models also predict the superheavy singlet exotics and the particles in the hidden sector. The singlets may be candidates as inflatoion fields. We think that it is interesting to construct inflation models using these singlets. The particles in the hidden sector can deduce the broken supersymmetry and are also worth researching.

Superheavy half integer charged particles seem to be very strange. But we should keep our mind open. Halfon is no more strange than axion or the dark matter. We have accepted the dark matter and suppose the existence of axion. Why can not we assume the existence of $S^{\pm 1/2}$?

Finally, we emphasize that, even if no signals of halfons in our universe are observed, this does not mean that the orbifold models should be excluded. It is possible that the number density of LHIC is too small because of the very low reheating temperature, and then the imprints of LHIC is too weak to be observed.

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